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Analysis and Improvements to the Green Falcon Solar Powered UAV

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Abstract

There has recently been a rapidly increasing interest in solar powered UAVs. With the emergence of high power density batteries, long range and low-power micro radio devices, airframes, and powerful micro-processors and motors, small/micro UAVs have become applicable in civilian applications such as remote sensing, mapping, traffic monitoring, search and rescue. The Green Falcon UAV is an innovative project from Queensland University of Technology and has been developed and tested during these past years. It comprises a wide range of subsystems to be analyses and studied such as Solar Panel Cells, Gas sensor, Aerodynamics of the wing and others. Previous test however, resulted in damage to the solar cells and some of the subsystems including motor and ESC. This report describes the repair and verification process followed to improve the efficiency of the Green Falcon UAV. The report shows some of the results obtained in previous static and flight tests as well as some of recommendations.

1. Unmanned Aerial Vehicles and Solar UAVs

Small UAVs have a relatively short wingspan and lightweight and can be operated by one or two pilots and seen theiur application to multiple domains including agriculture [1] wildlife monitoring [2]. One of the main limitations of these vehicles is endurance since most of them are not able to be on air more than 30 minutes or 1 hour [3]. Increasing battery sizes or the number of batteries, due to the weight restrictions, cannot solve these problems; weight is proportional to the endurance of the UAV. Several other methods to improve that characteristic are constantly being developed [3-6] . These include increasing the Aspect Ratio of the plane, reducing the drag coefficient or maximizing Lift over Drag ratio. One other alternative is the application of solar panels onto the wing of the plane to be able to supply power to the motor while flying [7, 8]. This project discusses an analysis and improvement to the Green Falcon UAV autonomy, power system and structure. The paper detailed the subsystem architecture along with a description of the operation, functions and interfaces. Detailed designs of the system hardware, software, and other specifications are presented, along with evidence supporting the justification of the design decisions where appropriate. A complete analysis of all the tests is also included in order to better understand the UAV behaviour during flights is performed. Full set of recommendations is given at the end of this report as next step to be followed to improve the efficiency of the plane.

2. System Architecture

The Green Falcon UAV was built with high quality components that bring efficiency, power and reliability. One of the main characteristics of this UAV is the thin and slender fuselage and wings (Figure 1) .

Figure 1. Green Falcon Solar Powered UAV

The system architecture (Figure 2) consists of the following.

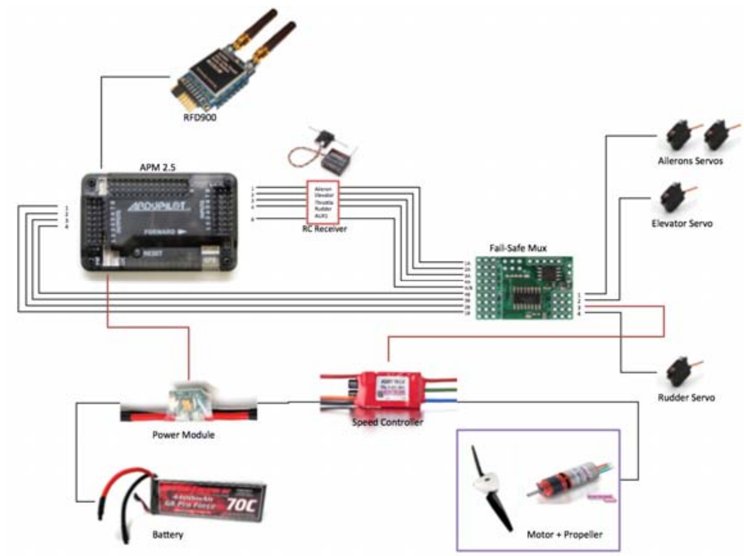

Figure 2: System Architecture

RC Transmitter: The Green Falcon UAV uses a DX8 by Spektrum and the Spektrum™ AirWare™ software with built-in telemetry, Spektrum Data Interface. The only 8-channel gives advanced capabilities, and the speed and precision of Spektrum 2.4GHz DSMX® control [9].

RC Receiver: The system uses a DX8 radio control and an AR8000 8-Channel DSMX Receiver from Spektrum. This 8 channel 2.4 GHz RC receiver has a input-to-output response with an 11-millisecond frame rate from stick input to servo output. The receiver is connected to the input terminal of the autopilot and failsafe board using a standard servo interface [9]

Control Surface Actuators: The Green Falcon has three different control surfaces: ailerons (two), elevator and rudder. These surfaces are controlled by Spectrum A7030 HV Thin Wing Servos. These servos have an axis, whose angular position can be precisely set in a limited range of less than one turn, generally around **90º**. The servo consists of a DC motor, a very high reduction ratio gearbox and electronics that steer the motor based on the angle measured with a potentiometer connected to the main axis.

Speed Controller (ESC): The Speed Controller used is a Koby 70 LV from Kontronik [10] . KOBY ESCs feature a powerful 3 A continuous current BEC that can easily handle peaks of up to 10 A. The output voltage of the synchronized BEC is adjustable from 5.6 V to 8 V. The Green Falcon however has faced several issues regarding the Speed Controller discussed later in this report.

Autopilot APM 2.5: The autopilot used is an ArduPilotMega (APM) [11]. Although there are newer version of APM, including the APM 2.6, the autopilot chosen for the Green Falcon UAV was the 2.5 version from 3D Robotics as this was readily available. This autopilot is a complete open source system, very light and with a high cost value ratio. It is connected to the radio (input) and to the rest of avionics (output) such as control surface activators and speed controller. One of the most important and used capabilities of the autopilot are the three main modes available during flight:

1. Manual Mode: the aircraft is completely flown by the pilot and the APM is only in charge of reading values and parameters, at the same time that it still connects the radio (input) and the rest of avionics (output).

2. Stabilize Mode: in this mode the aircraft can be flown as in manual mode, although this time stabilization assist the aircraft to be wings level and fly at a constant speed once no input is coming from the radio.
3. Auto Mode: In this mode, the aircraft is capable of flying autonomously following certain instructions previously set such as waypoint approach, changes in altitude and speed. These different commands or missions can be easily programmed and modified through APM Mission Planner 2.0.

Motor: The GF uses a KIRA 480-38 5,2:1 motor with gear box from Kontronik. It has a rotor diameter of 28 mm, a length of 79 mm, a shaft diameter of 5 mm and a gear shaft length of 20 mm. It weighs 185 g, has an internal resistance of 0.0095 Ohm, idle speed of 3800 r/min/V and a gear ratio of 5,2:1 [10]. This motor is recommended for the chosen speed controller and vice-versa.

Carbon prop: Different types of propellers can be found in the market. The Green Falcon UAV lands by skidding and therefore a set of folding propellers is used. A carbon prop 13x11" with a diameter of 33*28 cm from Aeronaut is used. Aeronaut CAM Carbon Folding Props are well known for their quality. They are made from a composite carbon material for extreme torsional rigidity with swept back tips and are therefore suitable for high performance.
As a back up, in case of failure or simply for increasing speed over power, a second set of propeller has been chosen. The Aeronaut CAM Carbon 17x11 is also available for flight testing the Green Falcon UAV.

Battery: The UAV uses a Thunder Power G8 Pro Force Lithium Polymer (LiPo) 4400 mAh 3S 70C battery. This 3 cell battery has a capacity of 4400 mAh, a voltage of 11.1 V and weighs 349 g. Thunder Power batteries have industry-leading highest energy and power density with the smallest size and lowest weight combined. They also have ultra-low internal resistance and ultra-fast charge rates. The main characteristics for this battery are [12]:

- Max Charge: 12C
- Max Cont. Discharge: 70C
- Max Burst Discharge: 140C
- Max Charge Current: 52.8A
- Max Cont. Current: 308A
- Max Burst Current: 616A
- Weight (grams): 348.8
- Dimensions H x W x L (mm): 24x 45 x 155

Telemetry System: The telemetry system uses an RFD900 which h is 900MHz, ISM band radio modem covering the 902 - 928 MHz frequency band. It is designed for long-range serial communications applications requiring best in class radio link performance. Software features include multi point capability to allow for networks of RFD900 modems [13]. It is small and very light with the following main characteristics

- Long range >40km depending on antennas and GCS setup
- 2 x RP-SMA RF connectors, diversity switched.
- Compatible with 3DR / Hope-RF radio modules.

3. Software: Mission Planner 2.0

The ground station consist of a laptop with the APM Mission Planner software is installed and which allows USB connection to the RFD900 telemetry system. The UAV operator can perform many tasks using this interface such as:

- creating a mission plan while setting waypoints based on Google maps
- sending commands to the autopilot and receiving real time flight information from the autopilot
- downloading mission log and data files
- configuring the autopilot’s settings depending on the airframe selected
- conducting flight simulations and creating full hardware-in-the-loop UAV mission simulations

Mission Planner is a free, open-source, community-supported application developed by Michael Oborne for the open-source APM autopilot project [14]. Mission Planner 2.0 allows access to the APM using a USB cable and by the telemetry system (RFD900 for the Green Falcon UAV). It also allows planning the desired mission thanks to a very simple Flight Plan mode that shows a map to set the points to be reached by the plane, as well as the altitude, speed and bank angle. Once accessed, one can monitor the status of the vehicle, view, analyse and record telemetry logs or operate the vehicle in one-person view. The software was used in every flight test for the Green Falcon UAV to record the UAV trajectory and flight data. The Mission Planner interface is shown in figure 3 below :

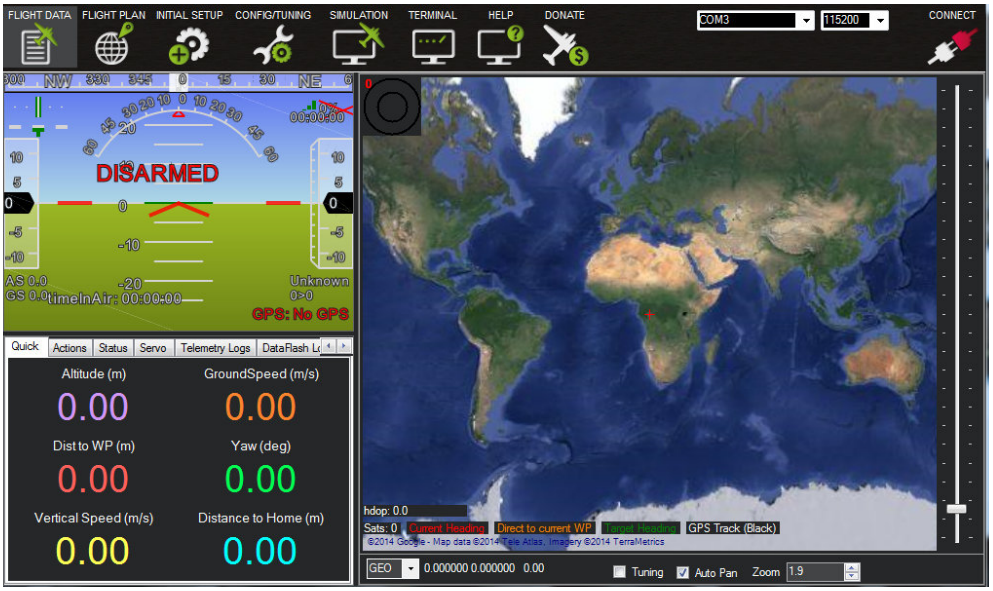

Figure 3: APM Mission Planer 2.0 interface.

4. Solar Wing Repairs

Before this project started the GF solar wing incurred damage in different parts with some of the solar panels broken (Figure 4) . Solar panels are extremely delicate and a minimum force onto their surface could easily result in a fracture. In addition, they are not very cheap and installation is very time consuming. Due to availability, not all of the panels could be replaced simultaneously and therefore we tested initially the efficiency of the remaining solar panels during flight and, once tested, consider the necessity of changing any, some, all of none of the panels.

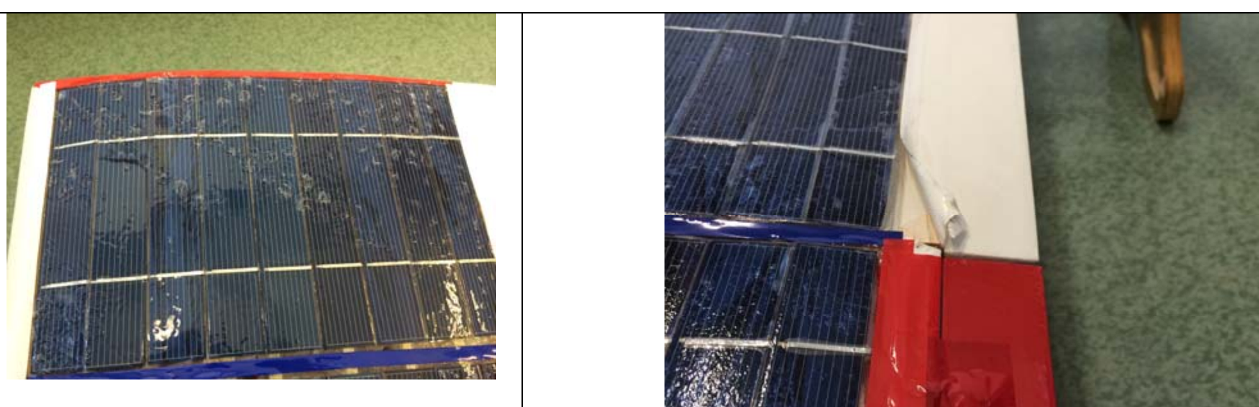

Figure 4: Damaged solar panels	5: Deattached tape before repair causing disturbanbces to th aroudn the wing

The second and most important damage of this wing was the tape used to connect solar panel cells with the body of the wing. The tape detached due to the airflow produced when flying the wing on a previous flight campaign. A hollow part of the wing was found below every single part of the solar panel cell where that problem occurred. Different solutions were taken into consideration including re-taping the entire wing or rebuilding a brand new solar panel wing. However, a solution was found by adding small pieces of wood to the hollow parts so that the new tape could easily and better stick to both the body of the wing and the solar panel cells. (Figure 6)

	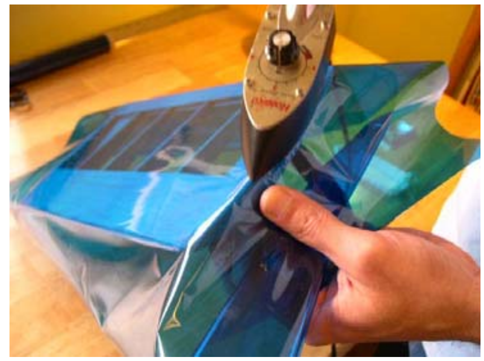
Figure 6: Solar panel wing repair process	Figure 7: Film ironing example

Figure 6 and 7 show the process followed to add wood to the critical zones. As it can be seen, the hollow parts were accessed from the bottom of the wing by cutting the film that covered it. This technique was preferred rather than accessing through the top of the wing due to the easy reparability of the film once the wood would be inserted. Once the repair was completed, a new film was needed using 'Film ironing' (Figure 6). This consisted on placing and extending the film over the bottom part of the wing and then irons it with a special filming iron machine. The final result is expected to be aesthetically identical as it was before the first flight, but this time with this new feature that would hopefully avoid the previous tapping issue.

5. APM 2.5 Configuration

The ArduPilotMega (APM) 2.5 allows the user to interact and modify the RC connection parameters, view and analyze the record telemetry logs, etc. The Green Falcon UAV has been programmed using two different APM 2.5 modules, both of them with the same configuration in case one of them would break and/or fails. In order to check the functionality of them, several ground tests were performed before final location inside the fuselage of the Green Falcon UAV. These tests included:

a) USB connection:

The APM 2.5 is connected to the Ground Control Station computer. APM Mission Planner 2.0 (Figure 8) can access the autopilot by selecting the current Serial Port in which it is connected and setting 115200 as a Baud Rate. The changes can be seen in the Primary Flight Display window when rolling or yawing or pitching the APM 2.5 module. If the module is yawed to the left, we will see that the green surface in the display will yaw to the right and vice versa, imitating a first person view from the plane. Other parameters such as absolute and relative altitudes or pitch roll and yaw angles were also checked .

Figure 8: Serial Port and Baud Rate confifurations using Mission Planer 2.0

b) Communications subsystem connection:
During this test the APM module was connected to the battery, the RC Receiver and telemetry, which allows communication to the Ground Control Station. An RC calibration test was performed to check that the values of the Throttle and control surfaces actuators were correct (Figure 9).

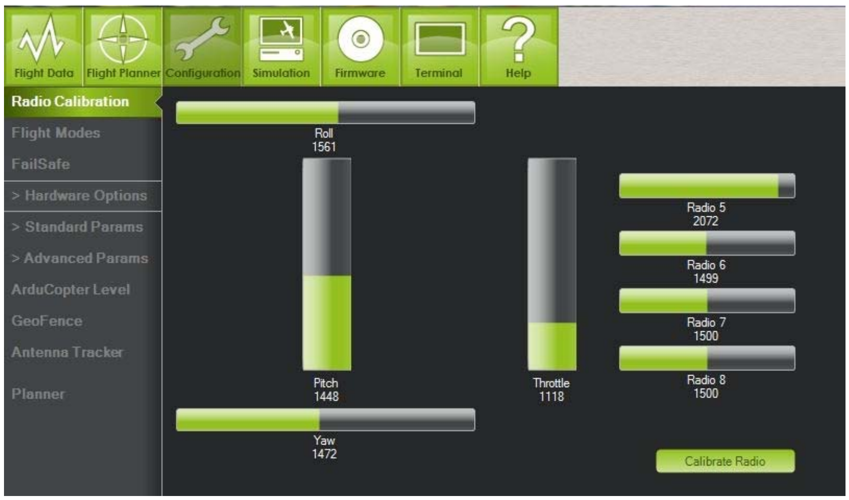

Figure 9: RC calibration using Mission Planner 2.0

6. System Test

6.1 System Test 1

The main objective of this flight was to test the manual mode of the aircraft in order to be able to safe it in case of autopilot failure An initial test was performed in order to assure a correct integration of all of the systems and to check that RC communications worked and the motor rotated in the correct direction. Results from this test show no issues in the integration process. After all the wiring was set, battery connected and RC communication was working, the control surfaces moved according to the RC commands and also that the APM 2.5 responded property while in Stabilize and Auto modes. The aircraft was manually yawed, pitched rolled from the ground and the control surfaces moved in such a way to stabilize the plane. Two flights were performed during this first testing day which resulted in two successful hand-launches that demonstrate that the power of the motor on the take-off. It also resulted in two successful flights in manual mode for 8 and 10 minutes. This first autonomous mission consisted on four waypoints with no issues but with a need to fine tune the PID gains. During the second flight the aircraft tracked to the waypoints successfully until the motor stopped after 5 minutes of flight. An emergency landing with no power was required and unfortunately no in-flight data could be taken during this flight due to failure in one of the telemetry system connection. The aircraft was inspected after landing and the temperatures of the motor and Speed Controller was much higher than normal. The rudder servo was also damaged during the forced landing. The aircraft was then taken to the workshop for further analysis and repairs.

6.2 System Test 2

The UAV was set up with a functional telemetry system that would let the Ground Control Station know the details of the aircraft during flight. During this test we conducted two new successful hand-launches and in-flight communication between APM 2.5 and Ground Control Station thanks to the RFD900 installed in the aircraft. This let the mission be modified and saved during flight. The test also resulted in autonomous flight. The plane completed autonomous flight until the motor stopped in mid-flight after 5 minutes. Extremely hot temperatures were once again recorded in the motor and Speed Controller. During a second flight, the motor stopped again after only 5-6 minutes. Apart from the unlucky events, the Green Falcon UAV was able to autonomous fly as shown in Figure 10. Although the UAV can track the waypoints, PID reconfiguration was needed in order to obtain a higher bank angle while in Auto mode so that the aircraft could perform sharper changes in direction.

Figure 1: Mission recorded at Christmas Creek during System test 2

6.3 System Test 3

A new Speed Controller was acquired by following the manual of the motor in an attempt to solve the problem. This new Speed controller was the exact same ESC as before (from the same brand as the motor) but a Koby 40A instead of Koby 70A. However, after a successful hand-launch the motor stopped again after 4.5 minutes. The results were very similar to test 2; a high temperature of the motor and speed controller, which had its case burnt. New analysis indicated possible causes for the motor and ESC failure are that the motor is damaged either mechanically or drawing too much current (more than 40A and even 70A) to the speed controller.

6.4 System Test 4

A new motor of the same brand was purchased and static bench test were performed. No wings were needed in this case since the purpose of the test was only to run the motor until either failure ESC or until the battery was fully discharged. Two charged batteries were tested. This time the motor did not stop after two consecutive 8 minute tests. Presently, the team is confident of having solved the problem, although some other potential causes were still taken into consideration such as APM, power module or batteries.

7. Conclusion and Future Work:

The Green Falcon UAV is an innovative project from Queensland University of Technology and has been developed and tested during these past years. It comprises a wide range of subsystems to be analyses and studied such as Solar Panel Cells, Gas sensor, Aerodynamics of the wing and others. Previous test however, resulted in damage to the solar cells and some of the subsystems including motor and ESC. This report presented the analysis and repairs made to the Green Falcon UAV during the July-November 2014 period. Structural improvements such as solar wing repair and the addition of a brand new motor, ESC and telemetry system are described. A detailed list of components and system architecture was provided to the reader and future user/developer of this aircraft

Furthermore, several ground tests have been done to check the performance of the aircraft. Unfortunately, not all of them resulted in satisfactory results. Future tests and changes should be focused on the following:

- Performing further flight tests with the Green Falcon 3 UAV system to test its capabilities in a real world environment and try to solve the ESC-Motor issue that causes motor failure.
- Installing the GX 2009 on the Green Falcon 3 UAV and perform an autonomous gas sampling mission
- Working on the reliability of the autonomy of the autopilot to be able to fly a gas monitoring mission in full autonomous mode at lower altitudes
- Developing a power board to efficiently manage the power distribution from the solar panels to charge the battery in flight

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